FVV PRIMEMOVERS. TECHNOLOGIES.

The FVV Transfer + Networking Event | Spring 2023

Knowledge and technology transfer | New research programme

Science for a moving society

Knowledge and technology transfer

With the Green Deal, Europe is aiming to make its economic system and the single market **sustainable, climate-neutral and resource-efficient** by 2050. Solutions for accelerating this »green transformation« can be implemented only on the basis of sound research and development results that do not negatively impact societal living standards, but instead sustain or even improve them. Accordingly, FVV's diversification strategy for the **energy systems and powertrains of the future** encompasses all energy converters and carriers that offer potential in this area. These include **battery electric solutions** as well as **fuel cells** and **thermal converters for alternative energy carriers**. In addition, research projects are being conducted on **circularity** and **material/resource efficiency**.

At the Transfer + Networking Event in Würzburg in spring 2023, FVV once again offered participants an ambitious programme on Industrial Collective Research into future technologies and, as always, an opportunity to discover how current research projects are progressing, discuss and exchange results and expand their network.

Climate-neutral and resource-efficient mobility

// see complete project data from p. 27

PROJECT 1434 · ICE2030
RESEARCH PRIORITY Hybrid Powertrains, Efficiency
EXPERT GROUP Engines **APPLICATIONS** Cars and Light-duty Vehicles

PROJECT 1412 · Zero Impact Tailpipe Emission Powertrains
RESEARCH PRIORITY Emissions **EXPERT GROUP** Zero-impact Emissions
APPLICATIONS Cars and Light-duty Vehicles

PROJECT 1411 · PEM-FC Cold Start Simulation
RESEARCH PRIORITY Development Tools **EXPERT GROUP** Fuel Cells
APPLICATIONS Transportation, Energy Systems

Alternative powertrains **with potential**

Without the fast research, development and introduction of sustainable powertrain systems, it will not be possible to protect the climate and use resources carefully. However, this challenge cannot be met by focussing solely on the energy conversion process, as it is not the powertrain technology itself that determines whether a future technology is sustainable, but rather the environmental behaviour or system efficiency of the entire energy supply and value chain (→ p. 23: system efficiency).

Within the scope of Industrial Collective Research, FVV therefore pursues a technology-neutral approach that considers all sustainable powertrains and energy carriers in equal measure. This mix allows the individual concepts to fully leverage their specific benefits for the applications and use cases areas in question.

The combustion engine after 2030

In this context, several presentations at the FVV meeting in Würzburg focussed on the future of the combustion engine or a hybrid powertrain after 2030. The presentation by Prof. Dr-Ing. André Casal Kulzer, Institute of Automotive Engineering (IFS) at the University of Stuttgart, summarised the results of the research project **›ICE2030: Limits of SI engine efficiency in hybridised powertrains‹.**

A total of four institutes were involved in the research: the Institute for Internal Combustion Engines and Powertrain Systems (vkm) at the Technical University of Darmstadt, the Institute for Internal Combustion Engines and Fuel Cells (ivb) at TU Braunschweig and the Chair of Thermodynamics of Mobile Energy Conversion Systems (TME) at RWTH Aachen University. The project committee was led by Arndt Döhler (Stellantis, Opel Automobile).

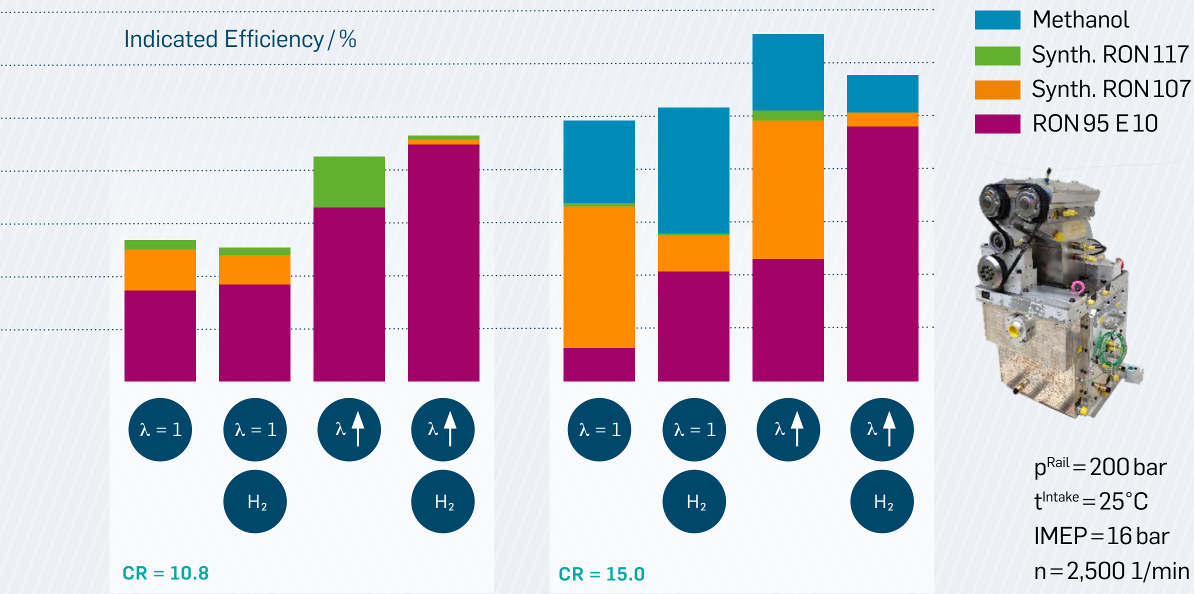


FIGURE 1

Indicated efficiency of different fuels at a compression ratio of 10.8 (left) and 15.0 (right) in $\lambda = 1$ operation and in lean operation – in each case with and without H_2 dosing // RWTH Aachen University | TME

»The goal of the research was to find out whether the potential efficiency of an optimised hybrid powertrain can be further improved and CO_2 emissions reduced by adding small quantities of H_2,« states Kulzer. Experimental investigations and simulations were performed to this end. For instance, tests on a single-cylinder engine showed the influence of adding H_2 on the combustion process when using various technologies for increasing efficiency. The combination of H_2 port fuel injection (PFI) and different directly injected liquid fuels was also investigated using the single-cylinder engine. At the same time, the researchers developed and validated simulation models for petrol or methanol-hydrogen mixtures on the basis of the measured data. To determine the potential of the engine concepts in different hybrid powertrains, various hybrid control strategies were implemented and optimised.

The project results show that adding H_2 on its own does not lead to a considerable increase in efficiency. Instead, significant efficiency gains are possible only in combination with very lean operation ($\lambda > 1.7$). »The benefits of a lean strategy combined with the addition of hydrogen depend heavily on the knock resistance of the initial fuel. The more knock-resistant the liquid fuel is, the less beneficial it is to add hydrogen,« explains Kulzer. The gains in efficiency totalled around 5 % for a better knock resistance when running at medium and high loads, and up to 15 % through dethrottling at low loads. Using a two-stage boosting concept allowed the advantages of the extremely lean concept to be extended throughout the entire engine map. Much higher degrees of efficiency were achieved with methanol than when using petrol or petrol-H_2 mixtures [FIGURE 1]. »Methanol combustion generally does not benefit from the addition of H_2, but fuels that are less knock-resistant than methanol do. The best levels of efficiency were achieved using a P2 hybrid with the lean methanol engine and a rule-based operating strategy with 45.2 % in the World-wide harmonized Light duty Test Cycle (WLTC) and 50.0 % for a Real Driving Emissions (RDE) route,« sums up Kulzer.

Basic principles for the development of vehicles whose emissions have no impact on air quality

At the Chair of Thermodynamics of Mobile Energy Conversion Systems (TME) at RWTH Aachen University, the **›Zero Impact Tailpipe Emission Powertrains‹** project led by Dr Frank Bunar (IAV) investigated which exhaust gas aftertreatment concepts could be used in the cars of the future to meet the zero-impact emissions limit from 2030 onwards. Zero-impact emissions (ZIE) are air pollutants (in this case nitrogen oxides) whose concentration is so small that they do not have a measurable negative impact on health or the environment.

In their presentation, Robert Maurer and Theodoros Kossioris from TME focussed above all on the technical solutions for two reference use cases, one being a car with a spark-ignition engine and the other being a light commercial vehicle (van) with a diesel engine. Seven specific traffic or driving situations were identified as test scenarios for testing ZIE conformity. These combined challenging driving conditions with unfavourable immission conditions, such as a high volume of traffic and a heavily built-up area such as the Neckartor area in Stuttgart.

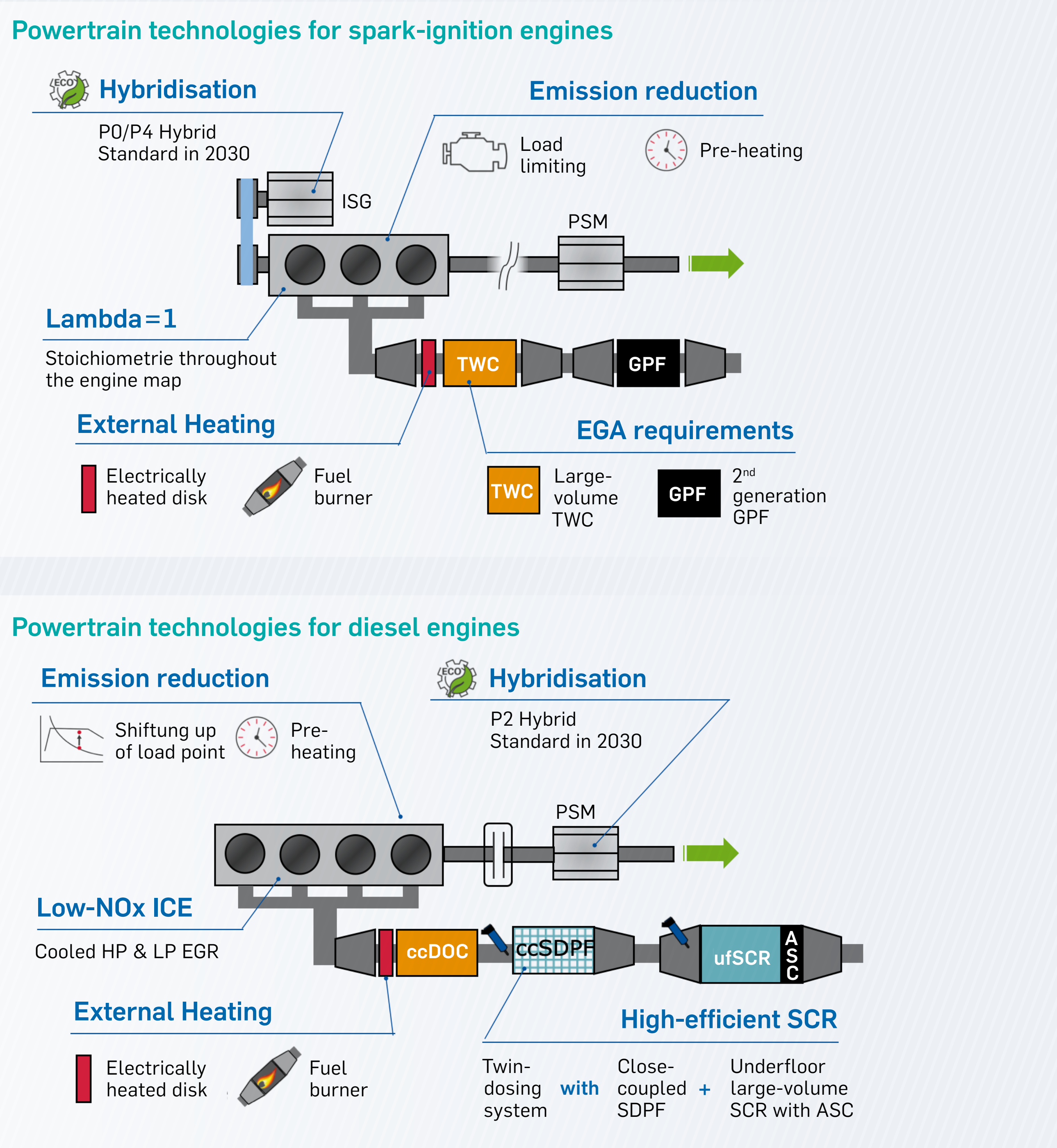


FIGURE 2

Actions for meeting ZIE requirements in spark-ignition engines (above) and diesel engines (below) // RWTH Aachen University | TME

In their initial state, both vehicles met the requirements for the latest emissions standard Euro 6d. However, in extreme urban driving scenarios with high degrees of cold starting, extended start-stop phases and short driving distances as well as in motorway journeys with a higher engine load, it was difficult to achieve the ZIE requirements in both engine concepts. As a result, technical optimisations were necessary.

The technological package for the spark-ignition engine consisted of $\lambda = 1$ combustion throughout the engine map, engine downsizing while retaining the current catalyst volume, a particulate filter and P0/P4 mild hybridisation with 48 V [FIGURE 2]. »Here, the hybrid technology whose main goal is to increase the efficiency of the system was also used to reduce pollutants as a synergy effect,« comments Maurer.

The diesel powertrain was also hybridised in the form of a P2 mild hybrid system with 48 V. »With the diesel engine there is also the option of engine-related measures such as exhaust gas recirculation (EGR) rates, optimised injection patterns and timings and shifting the load point using the electric motor. In some cases, it is possible to achieve a targeted reduction in the warm-up time of the exhaust gas aftertreatment components,« states Kossioris. The use of a selective catalytic reduction (SCR) system consisting of an SCR-coated diesel particulate filter in close proximity to the engine and a large-volume underfloor SCR with a twin-dosing system presented significant potential for lowering emissions in all operating states.

To further optimise emission behaviour for cold starts in both concepts, an electrically heated catalyst can be integrated. This allows the exhaust gas aftertreatment system to be heated to operating temperature quickly. However, pre-heating either before the journey or when moving off from standstill using only the electric motor is required to unlock the full reduction potential. »Alternatively, it can be sensible to use a fuel burner to heat the exhaust gas system,« says Kossioris.

Limiting the maximum engine load at the start of the journey is a cost-effective way of reducing emissions in both engine concepts. »However, it should be noted that this results in a noticeable performance limitation, which will certainly not be accepted by all drivers,« says Maurer. Increasing the catalyst volume has a positive impact on the cleaning effect on both the spark-ignition engine and the diesel engine, thus lowering emissions in high-load cycles.

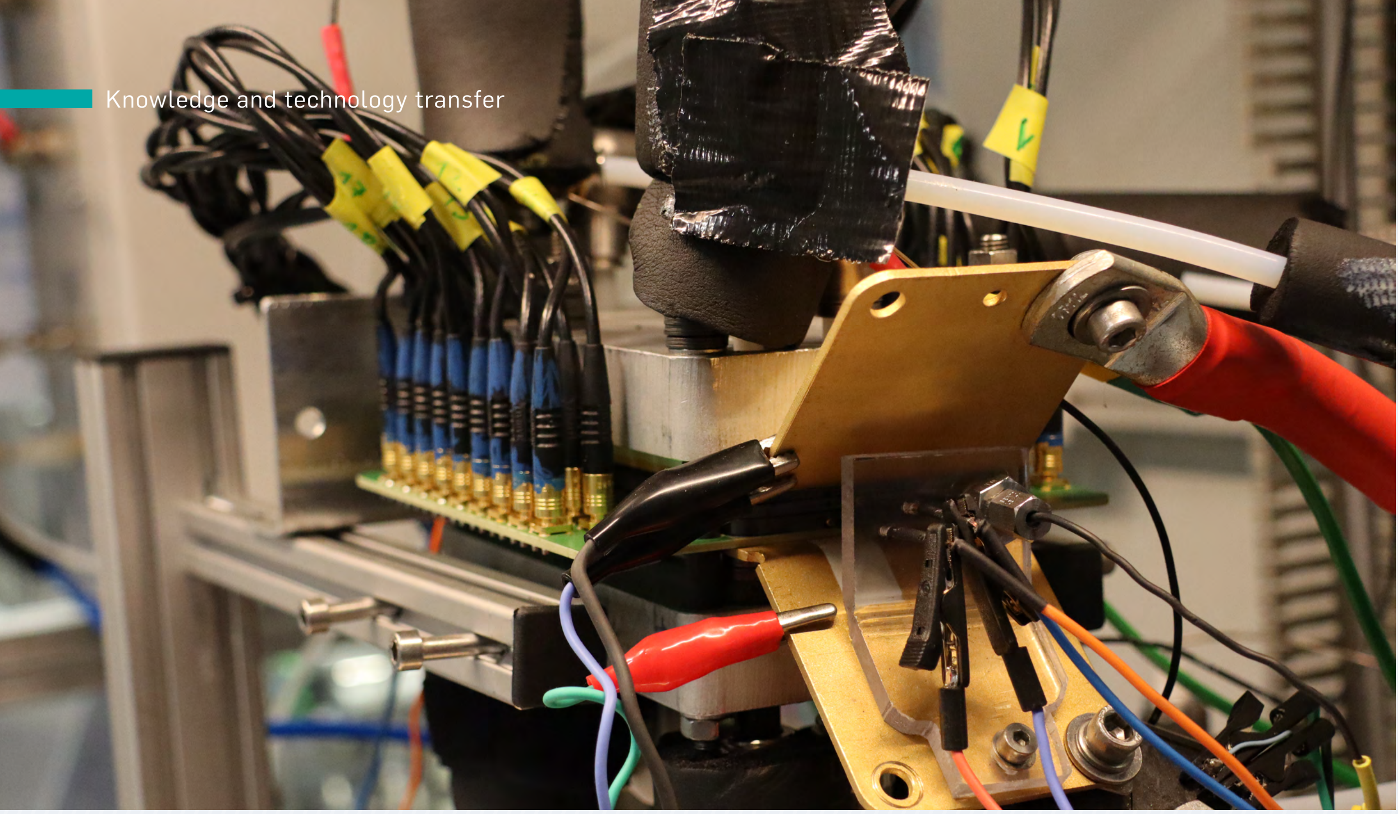


FIGURE 3
Test cell with sensors for locally resolved measurements on the fuel cell test bench // ZBT

Optimum cold start of the fuel cell

One of the current challenges in fuel cell technology is starting the vehicle at low ambient temperatures. In particular, water can impact the functioning of the fuel cells in a range of engine conditions: if the membrane dries out, this can lead to reduced proton conductivity; droplets can block channels and gas pores, and ice in the cells can inhibit electrochemical activity.

As part of the ›**PEM-FC Cold Start Simulation**‹ research project led by Dr Stefan Kaimer (Ford-Werke), a simulation model for the cold start of a fuel cell was developed at the Chair of Thermodynamics of Mobile Energy Conversion Systems (TME) at RWTH Aachen University and at Zentrum für BrennstoffzellenTechnik (the hydrogen and fuel cell centre; ZBT) in Duisburg. To this end, an existing model construction kit and the integrated 1D-2D stack model were enhanced so that liquid water in the channel and the structure of the flow field can be taken into account. »To ensure real-time capability, we have developed an intelligent process for predicting initial values for the numerical solver,« explains Matthias Bahr from ZBT. The system-level fuel cell simulation model was supplemented with detailed multi-dimensional CFD simulations. »The CFD model is crucially important for investigating the distribution of water within the cell layers, which are of particular interest during the cold start, and phase change phenomena such as condensation and evaporation,« adds Maximilian Schmitz from TME. To validate the simulation results, comprehensive

Read more:
MTZ report 06/2023
»Sustainable powertrain systems«
→ **www.fvv-net.de**

Read more:
MTZ report 02+03/2023
»Zero-impact emissons«
→ **www.fvv-net.de**

Read more:
ATZ report 11/2022
»Modular fuel cell system simulation environment«
→ **www.fvv-net.de**

measurements were performed on a segmented individual cell on a fuel cell test bench at ZBT [FIGURE 3]. »To do so, the behaviour of the cells was first tested under stationary operating conditions and then under realistic cold start scenarios. While doing so, localised measurements of the current density and high-frequency resistance were continuously taken and recorded,« explains Bahr. Comparisons between the stack model, the CFD model for the single cell and the measurements revealed that the two models can determine real behaviour highly accurately.

With the combined approach consisting of the improved stack and system model, the team then investigated cold starts. They discovered that the current density during a cold start has a significant influence on the heating speed. The formation of liquid water in the anode and cathode, on the other hand, is dependent on the stack's heating rate. //

Material and resource efficiency

// see complete project data from p. 27

PROJECT 1351 · TMF Crack Path Calculation for Turbocharger Hot Parts
RESEARCH PRIORITY Materials **EXPERT GROUP** Turbo Machines
APPLICATION Turbocharger

PROJECT 1444 · Modelling of Metal-graphite Composites (MeGrav II)
RESEARCH PRIORITY Materials **EXPERT GROUP** Turbo Machines
APPLICATIONS Optimised Plain Bearings, Mechanical Seals

Resource efficiency lowers material and energy consumption, **reducing environmental and climate impacts**

The components of modern powertrain and energy conversion systems that carry exhaust gas are exposed to high mechanical and thermal loads during operation. This can cause the components to crack, thereby reducing their service life. Researchers at TU Bergakademie Freiberg (TUBAF) and the Federal Institute for Materials Research and Testing in Berlin (BAM) have developed software that simulates and predicts the path of a fatigue crack. Novel metal-graphite composites enable higher service temperatures and thus the more efficient operation of machines, motors and engines. In an Industrial Collective Research project, researchers from TU Dresden devised a process control and design strategy for the general methodical development of these materials.

Within the scope of Industrial Collective Research, FVV and its projects help companies make their production more efficient in terms of resources and costs, increase the performance and longevity of components, thereby retaining materials in the circular economy for longer.

Looking into the future with simulations

Many components in engine and turbine construction, in particular hot-running components of turbochargers, are subjected to thermal and mechanical loads that vary over time. This leads to thermo-mechanical fatigue of the material and the formation of cracks in exposed places, potentially resulting in sub-critical crack growth and even component failure.

Until now, there was no way to predict how a detected crack will behave – i.e. whether it will grow and, if so, in which direction and at what speed. As such, there is considerable uncertainty during the computational design of components subject to such loads. In the field, components with detected cracks are therefore replaced as a preventive action, as the ongoing behaviour of the crack cannot be predicted with a sufficient degree of accuracy. This approach is difficult to justify in ecological or economic terms, especially as turbocharger housings can develop cracks that are not problematic to operation as they do not grow beyond a few millimetres. There is therefore a need for fracture-mechanical methods for evaluating the risk of further growth in detected cracks, and thereby for deciding whether a component can continue to be used or whether it needs to be replaced.

In the project ›**TMF Crack Path Calculation for Turbocharger Hot Parts**‹, a powerful calculation tool was developed for finite element simulation and predicting crack propagation in 3D components at TU Bergakademie Freiberg (TUBAF) [FIGURE 4]. The ProCrackPlast software is based on code initially developed at TUBAF for linear-elastic fracture mechanics (ProCrack). »In the field of thermo-mechanical fatigue, however, there are

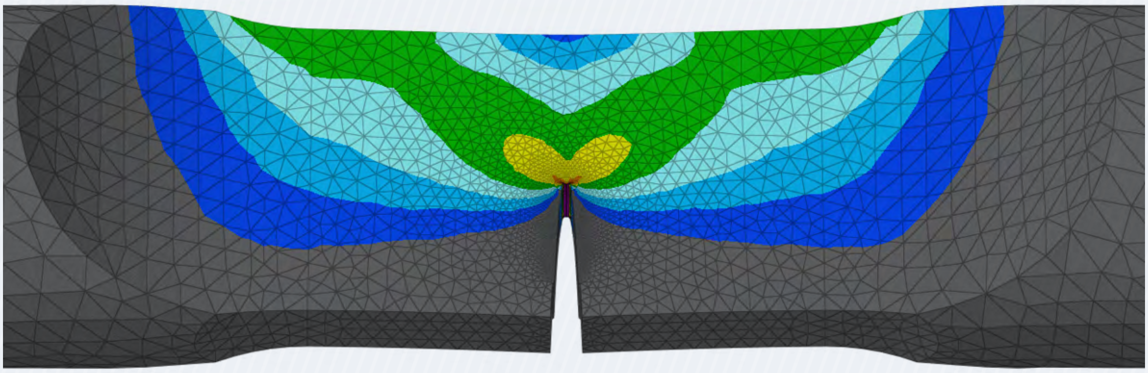


FIGURE 4

SENT sample: simulation result achieved using the simulation software developed in the project. Specifically, the image shows the distribution of stress during the propagation of fatigue cracks in a SENT (single-edge notched tension) sample // TU Bergakademie Freiberg | IMFD additional effects that need to be taken into account, such as a tendency to creep,« comments Professor Björn Kiefer from the Institute of Mechanics and Fluid Dynamics (IMFD). This is why inelastic material models were also used in the expanded simulation environment, some of which had been developed as part of a previous project at the Federal Institute for Materials Research and Testing in Berlin (BAM). The experimental data required by the simulation software to calibrate and validate the models was gathered at BAM during sophisticated investigations [FIGURE 5].

Flat tensile specimens with cracks were used to determine crack growth at temperatures between 20 and 700 degrees Celsius, thereby creating robust data for quantifying crack propagation. In addition, the researchers simulated all tests using a finite element-based calculation procedure.

ProCrackPlast can now be used in development on a cross-application basis – i.e., wherever combustion engines with turbochargers or turbines with housings made of the typical cast iron material NiResist D5S are deployed. The material parameters are pre-built into the software. The user enters the geometry of the component, adds the expected mechanical and thermal load change, and receives a prediction for the probable behaviour of a crack.

Industrial partner Rolls-Royce Solutions coordinated the project, and Dr Andreas Koch, Senior Manager Structural Mechanics & Thermal Analyses, is extremely satisfied with the developed simulation environment: »For us, it is also interesting to know in which direction a crack is growing and how it will develop if I drive a few thousand cycles more than was actually planned.« Engineers can take several design-related actions

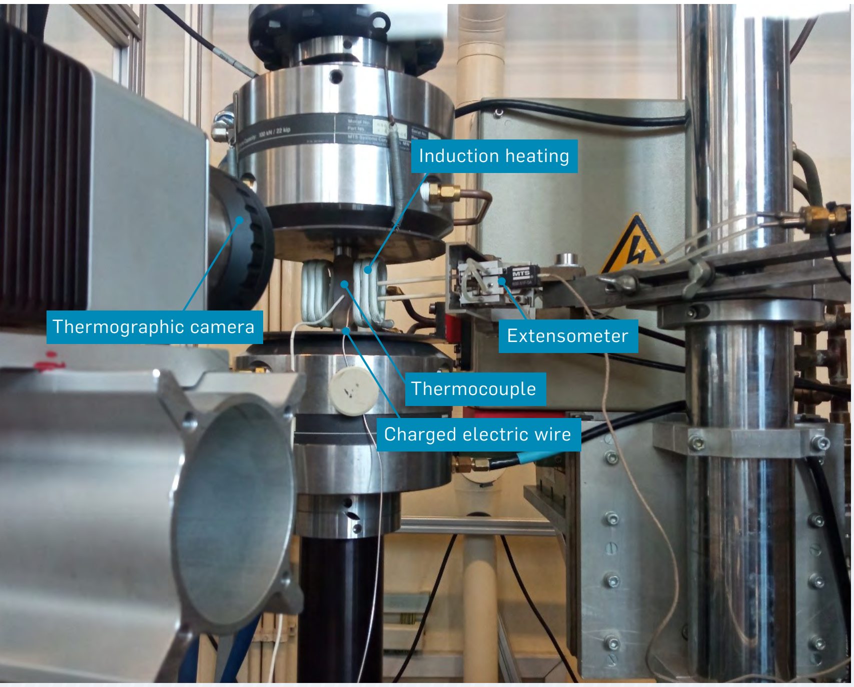


FIGURE 5
BAM test bench: all crack propagation tests were performed in air on a servo-hydraulic testing machine
// Bundesanstalt für Materialforschung und -prüfung

to minimise crack formation: »During the design phase, relevant areas can be designed for lower thermomechanical loads by dimensioning the wall thickness in critical areas to suit the respective load,« explains Dr Koch. As such, ProCrackPlast means maintenance intervals can be extended, while expensive components no longer need to be replaced as a precaution in the event of acceptable cracks – saving time in the process.

The calculation software has already been used for design at Rolls-Royce Solutions and was applied to a custom geometry. Now it is important to gather experience according to Koch. In the future, the researchers in Freiberg want to further improve the software and methodology, optimise the models' precision and conduct more reference experiments. Although only one material was analysed during the project, Professor Kiefer sees the need to perform tests using other materials to thus validate the method's transferability.

The software including user manual is available to all FVV member companies, alongside the identified material parameters and fatigue crack models. A live demonstration of the software was conducted and questions answered during a workshop. Transferring the results to industry is a simple process: vehicle manufacturers forward the corresponding specifications to the turbocharger manufacturers, while fabricators of exhaust gas systems or computational service providers also benefit directly from the software. »Until now planning has erred on the side of caution, with components being designed with thicker walls which are then heavier than they need to be,« explains Dr Koch. The better the simulation, the less conservative manufacturers will need to be when building parts in the future, saving weight, material and costs.

However, the limits of the evaluation concept also became apparent during the course of the project. One of the problematic aspects is describing creep strain accumulation, creep damage and oxidation-induced embrittlement, which primarily occur at high temperatures and long hold times. Approximate approaches have been suggested for these cases, but these still need to be validated through appropriate long-term tests. »We were also unable to sufficiently investigate the influence of alternating loads of tension, thrust and torsion (mixed-mode loading) on the growth of fatigue cracks. Thus, there is certainly potential for a later project concerning this,« says Professor Kiefer. The ProCrackPlast software contains plausible fracture hypotheses for such load cases, but these still need to be specified.

FIGURE 6

Prototype flange sleeves made of graphite infiltrated with aluminium or magnesium // TU Dresden | ILK

Modern metal-graphite composites for more efficient machines and engines

Advances in performance and efficiency in mechanical and plant engineering mean that materials are exposed to higher working temperatures. On plain bearings and mechanical seals in particular, increasing speeds or system pressures mean that higher operating and emergency running characteristics need to be guaranteed. As the system temperature rises, however, increased fretting occurs in the friction surfaces, which results in high maintenance and repair costs and wear-related downtimes and failures.

Conventional plain bearing materials such as polyimides, bronze or white metals reach their mechanical limits at higher temperatures: the disadvantage of the frequently used polymers is the relatively low continuous service temperature of no more than 250 degrees Celsius.

In the future, it will be possible to operate machine tools, compressors, combustion engines and aircraft engines only through using materials that are resistant to wear and high temperatures.

In the project **›Metal-graphite Composites for Plain Bearings (MeGrav I)‹** (FVV project number 1330), aluminium or magnesium alloys were pressed into the pores of graphite under high pressure using a squeeze-casting process. This metal-infiltrated graphite is seen as a promising alternative thanks to its self-lubricating properties, its high-temperature stability and its good mechanical characteristics. In the follow-up project **›Modelling of Metal-graphite Composites (MeGrav II)‹** René Füßel and his team from the Institute of Lightweight Engineering and Polymer Technology (ILK) at TU Dresden are now evaluating how high temperatures influence the material. In addition, a process control and design strategy for developing metal-graphite products is being drawn up for the first

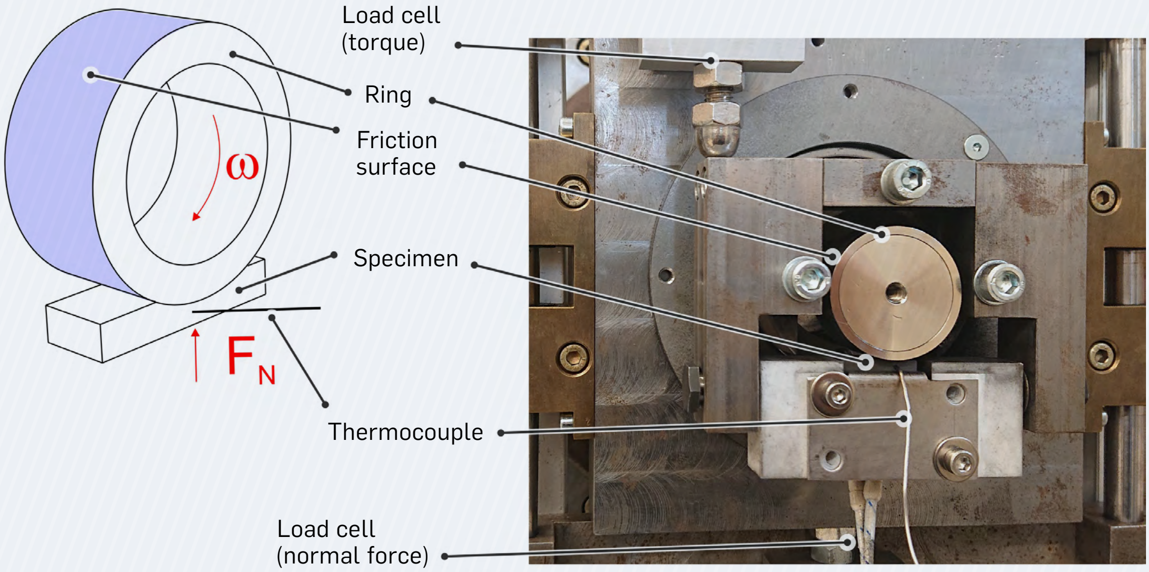


FIGURE 7

High-temperature friction test bench with in-built block-on-ring tester // TU Dresden | ILK

time. As the industrial partner, Rolls-Royce Deutschland is providing the sample material and the requirements catalogue [ABBILDUNG 7]. One typical field of application for metal-graphite composites is plain bearings in compressors, explains Dr Susanne Schrüfer from Rolls-Royce Deutschland: »If we can achieve a continuous service temperature of 300 degrees Celsius or more in the future, that would be a big step forward. But everything above 250 degrees is a success.«

The influence of the manufacturing parameters on the final product should be investigated in the design phase: »We want to determine how the manufacturing parameters vary and identify their influence on the characteristics,« says Füßel, adding: »In other words, if the material is infiltrated at 670 bar, it will have a certain sliding friction coefficient.« The different infiltration grades are to be evaluated in terms of their physical properties in order to develop an appropriate quality method. To this end, semi-finished products with different parameters were manufactured from the raw graphite.

René Füßel's team has performed around 450 friction tests and 250 mechanical tests, including three-point bending tests, over the last few months. With a cycle time of approximately one day per test specimen, this is a time-consuming process, despite having two machines running in parallel. The researchers are conducting the tests from room temperature up to approximately 300 degrees Celsius – and even up to 450 degrees Celsius for different ageing conditions [FIGURE 8]. One goal of the modelling is to predict wear rates based on parameter variations in the process. »At a low infiltration pressure, the sliding friction coefficient should be lower, while at higher pressures it should be higher,« says Füßel. He believes this will make it possible to predict the required maintenance intervals in the future: how long can machines be operated before they need servicing and before wear parts need to be replaced?

According to René Füßel, it is already becoming evident that there are no expected significant differences in mechanical or tribological characteristics thanks to the extremely robust manufacturing process. Even fluctuating manufacturing parameters barely impact the performance of the material. »This is a very positive result for the application itself, as we always achieve consistently high quality. But it makes modelling more difficult,« explains Füßel.

With the gathered data, the team will press ahead with the modelling over the coming months. Without wanting to pre-empt the final report, Füßel makes the following comment: »There are hard application limits, but within these limits the system is highly stable.« During the tests, it was revealed that although the magnesium-infiltrated graphite has a lower wear rate, magnesium is less resistant to heat than aluminium. Moreover, it has a tendency to spontaneously ignite at very high temperatures of more than 500 degrees due to its reactivity – which is why several companies are reluctant to process magnesium.

The research results will benefit bearing manufacturers, but also mechanical and plant engineers and material suppliers that manufacture the metal-infiltrated plain bearings and seals in an injection moulding or die casting process. The machines used to produce polymer or graphite seals up to now can continue to be used in the future. While, as Dr Schrüfer explains, the first plain bearings and seals made of the new material could be used relatively quickly in the mechanical and plant engineering or automotive industry, it will take several years to transfer the results to the aviation industry: »This requires suppliers that deliver the desired quality, acceptance standards and suitable quality assurance methods. Depending on the application, this can take at least three years.« //

Around **250** participants from industry and science joined in lively discussions

A total of **24 projects** on scientific and technological foundations for climate neutrality and zero-impact emissions from sustainable energy conversion systems were presented

On **5 October 2023** we will meet again in Würzburg for the next FVV Transfer + Networking Event

Science for a moving society

Keeping an open mind **for the future**

Around 250 attendees from companies, research bodies and associations came together in Würzburg to learn about the latest results of ongoing and recently completed FVV research projects. A multitude of informative presentations promoted the exchange of knowledge on future topics such as sustainability, efficiency, climate protection and the conservation of resources (→ p. 27: research directory). The participants gained valuable support and a manifold stimuli for their own research and development activities.

In order to meet the demands of research in the future, too, FVV has restructured its research portfolio and research groups (→ p. 34: expert groups and fields of research (ToR)). The pre-competitive Industrial Collective Research organised by FVV thus provides the foundation for the development of even more environmentally friendly and resource-saving engines, hybrid powert-rains, fuel cells, turbines, compressors and the corresponding energy carriers.

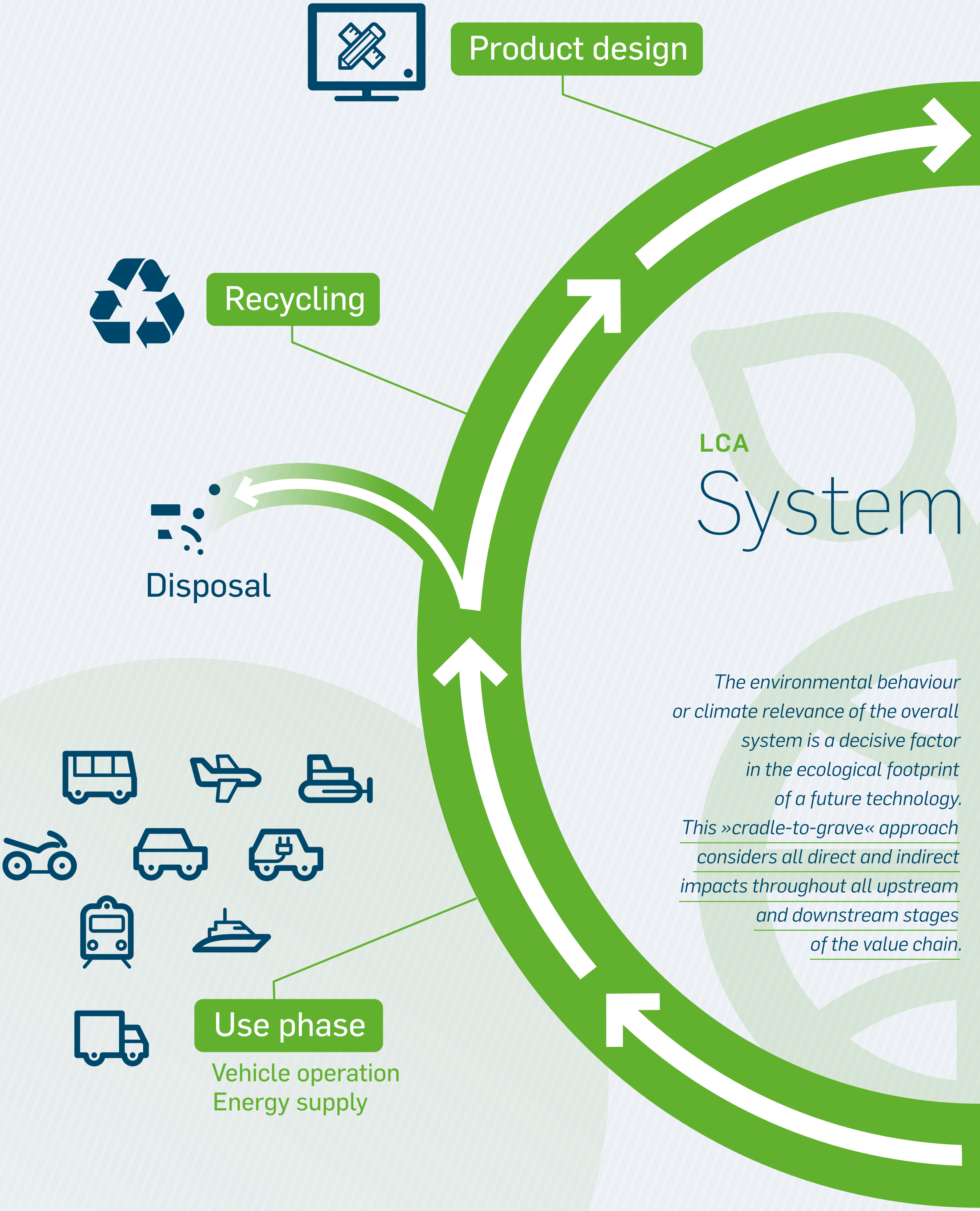
Live conferences are still a key medium for exchanging information and ideas and for expanding the scientific network. FVV's next transfer event is planned for 4 to 6 October 2023, and will once again take place in Würzburg.

See also:
The FVV Transfer + Networking Event | Autumn 2023
→ www.fvv-net.de/en/

How a focus on system efficiency **accelerates the green transformation**

During its research activities for climate neutrality and zero-impact emissions, FVV always pursues a facts-based, open-minded approach. Accordingly, FVV's diversification strategy for the energy systems and powertrains of the future encompasses all energy converters and carriers that offer potential in this area. These include battery electric solutions as well as fuel cells and thermal converters for alternative energy carriers. All technologies are analysed and evaluated objectively. After all, the environmental behaviour or climate relevance of the overall system is a decisive factor in the ecological footprint of a future technology.

For the International Vienna Motor Symposium in April 2023, FVV has summarised the key propositions of its comprehensive studies on life-cycle analyses in the mobility sector in an information paper. The new paper also features FAQs on the basic technical and economic framework conditions for this series of studies.

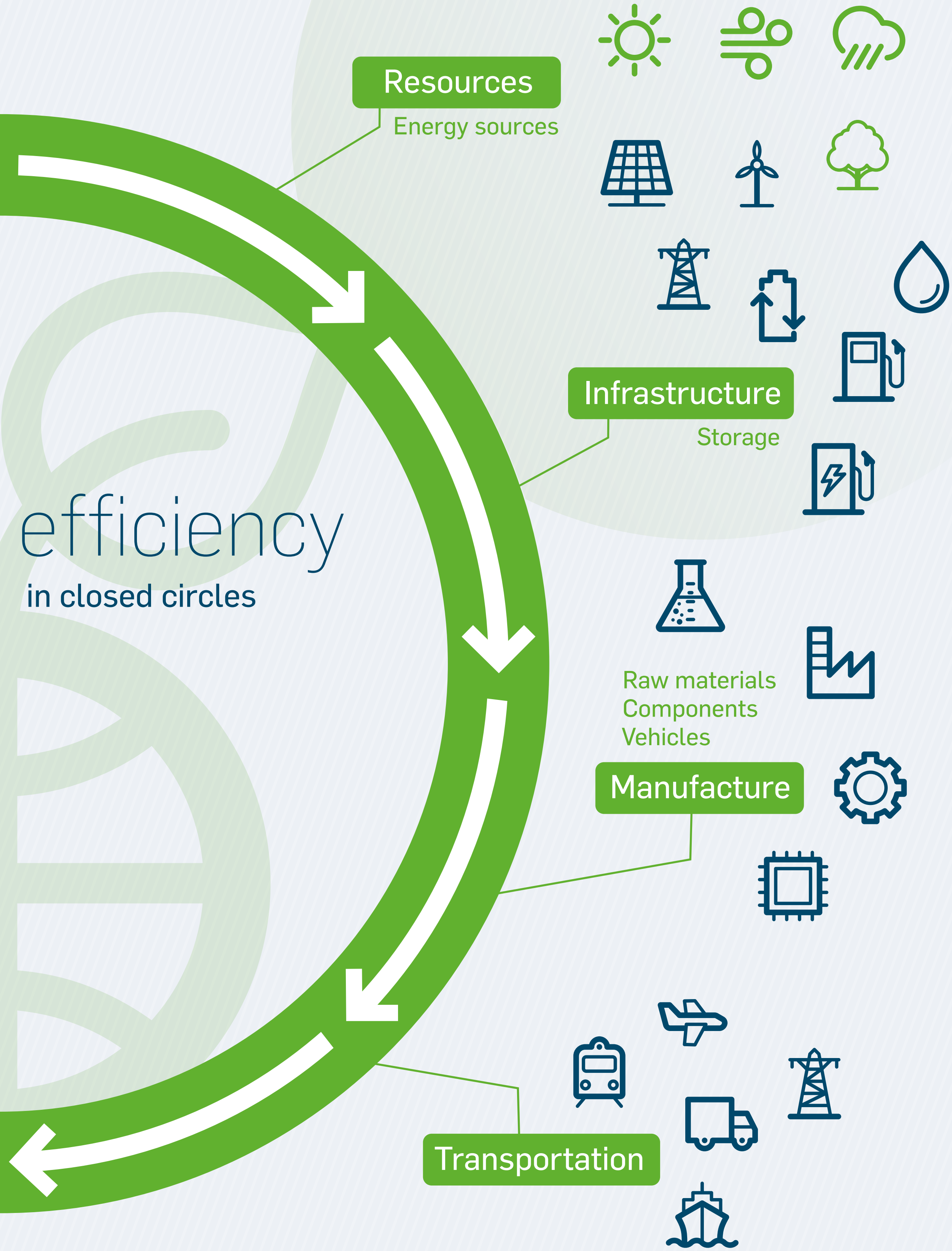


LCA

System

The environmental behaviour or climate relevance of the overall system is a decisive factor in the ecological footprint of a future technology. This »cradle-to-grave« approach considers all direct and indirect impacts throughout all upstream and downstream stages of the value chain.

efficiency
in closed circles



FVV calls for society and the political arena to actively promote the diversification of energy carriers and converters in the European transport sector.

To achieve the climate goals of the Paris Agreement, the EU has made a binding legal commitment to achieve climate neutrality and net-zero emissions in 2050 – i.e. no more CO_2 is to be emitted than can be absorbed by forests or through other means. By 2030, net greenhouse gas emissions are to be lowered by at least 55 % compared to 1990. In addition, Germany has set itself the goal of emitting 65 % less CO_2 in 2030 than in 1990 and of achieving climate neutrality as early as 2045. FVV supports the ambitious climate goals set by Germany and the EU. To implement these quickly and effectively, it is especially important to pursue all available technological solutions for climate neutrality in equal measure and to evaluate them on the basis of facts. The benchmark for using the respective energy carrier and converter must be its environmental impact throughout its entire life cycle assessed within the scope of a detailed life-cycle assessment (LCA) based on a global, cross-industry and cross-sector perspective. This is known as the »cradle-to-grave« approach and takes all CO_2 emissions into account without any exclusions. In the case of a vehicle, it not only includes the use of the vehicle (tank-to-wheel), but also its manufacture, provision of the propulsion energy (well-to-tank), building and operating the necessary infrastructure and recycling the vehicle after the end of its life cycle (end-of-life).

As part of a comprehensive series of studies, FVV has performed an LCA of the various technologies for saving CO_2 emissions for the European transport sector. All industries involved in the overall energy chain were involved, plus research institutes focussing on technology and economics. The resulting studies provide the most comprehensive data pool created to date for evaluating the CO_2 relevance of future energy and powertrain technologies for the mobility sector. The heart of these investigations is the potential of various energy carriers and converters for lowering CO_2 emissions. Here, the partners considered the entire »cradle-to-grave« CO_2 chains and all energy carriers and converters that are currently deemed to offer potential for reducing CO_2 and are the focus of the research and development activities of research institutes, engineering service providers or industrial companies (→ FVV Transfer Event report for autumn 2022, p. 14–19).

The results of the studies can be summed up in three key points:

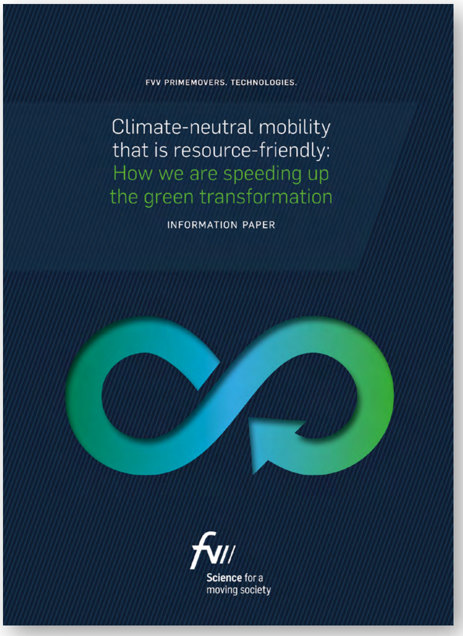
- **All solutions offer comparable potential for reducing CO_2.**
- **The speed of introducing and ramping up new technologies is decisive.**
- **The rapid defossilisation of the transport sector requires a diversification of technologies.**

This diversification gives politicians, scientists, society and industry the tools they need to evaluate new developments for dispensing with fossil fuels as quickly as possible and adopting carbon-neutral technologies for the various sectors, and to launch them on the market.

Diversification also creates redundancies among the energy carriers and converters, which has the effect of safeguarding the goal of climate neutrality by 2050 against factors that are difficult or impossible to estimate or assess. If, for example, a geopolitical problem or an issue with the supply of raw materials delays the ramp-up of one technology, this can be largely compensated by using a different technology.

FVV therefore calls for society and the political arena to actively promote the diversification of energy carriers and converters in the European transport sector. If additional renewable energy carriers are not considered, we are in danger of leaving potential for reducing CO_2 emissions unused, failing to defossilise energy carriers as quickly as possible and therefore unnecessarily increasing cumulative CO_2 emissions.

Political decisions and specifications should be based on a comprehensive LCA, while existing laws and guidelines must be examined on the basis of this and amended where needed. Moreover, it is crucially important to define intermediate steps on the road to carbon neutrality in the EU by 2050 and to establish suitable mechanisms to assess their achievement.



See also:
Further information in the science story »How we are speeding up the green transformation«
→ www.fvv-net.de/en

Proceedings R 604
The FVV Transfer + Networking Event | Spring 2023

→ www.themis-wissen.de

NR	› TITLE › FUNDING ORGANISATION	› RTD PERFORMERS › PROJECT COORDINATION	› PROCEEDINGS › FINAL REPORT
1318	› **Air Insulation Diesel Engine:** Efficiency increase by means of air insulation through targeted spray and combustion chamber design and reduction of combustion duration in diesel engine › FVV	› Prof Dr Jesús Benajes (CMT, Universitat Politècnica de València) Prof Dr Thomas Koch (IFKM, KIT Karlsruhe) › Dr Patrick Gastaldi (Aramco Fuel Research Center)	› R604 (pp. 348–394) › H1332 (2023)
1321	› **Working Cycle Dissolved Turbine Efficiency in Turbochargers:** Transient efficiency, modeling for engine process simulation, one- and double-flow turbine housing › FVV/DFG	› Prof Dr Bernd Wiedemann (ILS, TU Berlin) › Dr Mathias Vogt (IAV GmbH Ingenieurgesellschaft Auto und Verkehr)	› R604 (pp. 67–99) › H1330 (2023)
1350	› **Fatigue Influence Braze Quality:** Development of design concepts for the assessment of the fatigue strength of brazed joints under consideration of process-related brazed joint conditions › BMWK/AiF	› Prof Dr Tobias Melz (Fraunhofer LBF) Prof Dr Kirsten Bobzin (IOT, RWTH Aachen) Prof Dr Wolfgang Tillmann (LWT, TU Dortmund) › Prof Dr Matthias Türpe (MAHLE International GmbH)	› R604 (pp. 37–66) › H1309 (2022)
1351	› **TMF Crack Path Calculation for Turbocharger Hot Parts:** Numerical simulation and evaluation of crack propagation in time and space of exhaust turbocharger hot parts under thermomechanical fatigue loading with finite element programs › BMWK/AiF	› Prof Dr Ulrich Panne (Bundesanstalt für Materialforschung und -prüfung, Berlin) Prof Björn Kiefer (IMFD, TU Bergakademie Freiberg) › Dr Andreas Koch (Rolls-Royce Solutions GmbH)	› R604 (pp. 579–613) › H1320 (2023)
1354	› **Industrial Radial Compressor with Wide Operating Range:** Experimental investigation of the flow instabilities in the part-load range of an industrial radial compressor controlled by inlet swirl with a high map width › BMWK/AiF	› Prof Dr Peter Jeschke (IST, RWTH Aachen) › Dr Matthias Schleer (Howden Turbo GmbH)	› R604 (pp. 428–454) › H1310 (2022)
1371	› **Robust Fracture Deformation Parameters:** Robust evaluation of fracture deformation parameters to use the creep ductility within advanced lifetime assessment concepts › AVIF/FVV	› Prof Dr Matthias Oechsner (IfW, TU Darmstadt) Prof Dr Arjan Kuijper (GRIS, TU Darmstadt) Prof Dr Stefan Weihe (Materialprüfungsanstalt (MPA), Universität Stuttgart) › Dr Torsten-Ulf Kern (Siemens Energy Global GmbH & Co. KG)	› R604 (pp. 677–710) › H1342 (2023)
1374	› **Fuel Influence on Particulate Characteristics:** Influence of oil and fuel components on soot formation in gasoline engines › BMWK/AiF	› Prof Dr Thomas Koch (IFKM, KIT Karlsruhe) › Dr Wolfgang Samenfink (Robert Bosch GmbH)	› R604 (pp. 241–277) › H1325 (2023)
1379	› **Tribomaps Friction Enhancing Laser Structures:** Development of tribomaps for friction enhancing laser structures › BMWK/AiF/FVV	› Prof Dr Alexander Hasse (IKAT, TU Chemnitz) Prof Dr Udo Löschner (LHM, Hochschule Mittweida) › Dr Anton Stich (AUDI AG)	› R604 (pp. 6–36) › H1329 (2023)
1383	› **Acoustic Emissions into Discharge Pipes II:** Development and validation of a measurement method for determining the sound power radiated into the discharge line by a centrifugal compressor › FVV/DFG	› Prof Dr Lars. Enghardt (ISTA, TU Berlin) Prof Dr Peter Jeschke (IST, RWTH Aachen) › Vera Kress (MAN Energy Solutions SE) Dr Irhad Buljina (MAN Energy Solutions SE)	› R604 (pp. 395–427) › H1335 (2023)

NR	› TITLE › FUNDING ORGANISATION	› RTD PERFORMERS › PROJECT COORDINATION	› PROCEEDINGS › FINAL REPORT
1386	› **Turbo High Temperature Steel:** Increase of power density in turbo applications by new material concepts for high temperature conditions and functional integration in planetary gear stages › BMWK/AiF	› Prof Dr Christian Brecher (WZL, RWTH Aachen) Prof Dr Rainer Fechte-Heinen (IWT, Leibniz-Institut für Werkstofforientierte Technologien Bremen) › Dr Markus Dinkel (Schaeffler Technologies AG & Co. KG)	› R604 (pp. 614–644)
1392	› **Materials Applications FeAl (WAFEAL):** Material applications for iron aluminide (FeAl), (WAFEAL) › BMWK/AiF	› Dr André Schievenbusch (Access e.V. (ACC), Aachen) Prof Dr Ulrich Panne (Bundesanstalt für Materialforschung und -prüfung Berlin) › Susanne Mosler, Dr Dan Roth-Fagaraseanu (Rolls-Royce Deutschland Ltd & Co KG)	› R604 (pp. 645–676) › H1322 (2023)
1397	› **Prediction of Gas Turbine Emissions:** DNS-driven development of predictive LES models for gas turbine emissions › DFG/FVV	› Prof Dr Heinz Pitsch (itv, RWTH Aachen) › Dr Ruud Eggels (Rolls-Royce Deutschland Ltd & Co KG)	› R604 (pp. 455–489) › H1337 (2023)
1400	› **Deposits from AdBlue II:** Investigation and modelling of deposit formation during exhaust gas aftertreatment by injection of AdBlue into the SCR catalytic converter › BMWK/AiF-CORNET, BMK/FFG, FVV	› Prof Dr Olaf Deutschmann (ITCP, KIT Karlsruhe) Prof Dr Bernhard Geringer (IFA, TU Wien) › Raimund Vedder (ehemals Atlanting GmbH)	› R604 (pp. 210–240) › R1324 (2023)
1403	› **eSpray:** Injection, mixing and autoignition of e-fuels for CI engines › BMWK/AiF-CORNET, BMK/FFG, FVV	› Prof Dr Michael Wensing (FST, FAU Erlangen-Nürnberg) Prof Dr Christof Schulz (EMPI, Universität Duisburg-Essen) Prof Dr Bernhard Geringer (IFA, TU Wien) Dr Paul Miles (CRF, Sandia National Laboratories, Livermore, California) Prof Dr Dong Han (IAEPT, Shanghai Jiao Tong University) › Dr Uwe Leuteritz (Liebherr Components Deggendorf GmbH)	› R604 (pp. 312–347) › H1333 (2023)
1411	› **FC Cold Start:** PEM-FC cold start simulation › FVV	› Dr Peter Beckhaus (ZBT Duisburg) Prof Dr Stefan Pischinger (tme, RWTH Aachen) › Dr Stefan Kaimer (Ford-Werke GmbH)	› R604 (pp. 278–311) › H1336 (2023)
1412	› **Zero Impact Tailpipe Emission Powertrains:** Particulate emissions with regard to the complete vehicle › FVV	› Prof Dr Stefan Pischinger (tme, RWTH Aachen) › Dr Frank Bunar (IAV GmbH Ingenieurgesellschaft Auto und Verkehr)	› R604 (pp. 185–209) › H1334 (2023)
1422	› **Extended Operation Range of YSZ:** Extension of the YSZ thermal barrier coating loading temperature by alternative spraying technology and modification of the chemical composition › DFG/FVV	› Prof Dr Robert Vaßen (IEK-1, Forschungszentrum Jülich GmbH) PD Dr Mathias Galetz (DECHEMA-Forschungsinstitut Frankfurt) Prof Dr Matthias Oechsner (IfW, TU Darmstadt) › Dr Arturo Flores Renteria (Siemens Energy Global GmbH & Co. KG)	› R604 (pp. 729–758)

NR	› TITLE › FUNDING ORGANISATION	› RTD PERFORMERS › PROJECT COORDINATION	› PROCEEDINGS › FINAL REPORT
1423	› **Combined Dynamical Analyses – Analytics:** Non-linear blade vibration analysis with combined mistuning effects of geometry and excitation for stationary and transient operations › BMWK/AiF	› Prof Dr Jörg Wallaschek (IDS, Leibniz Universität Hannover) › Dr Andreas Hartung (MTU Aero Engines)	› R604 (pp. 546–579)
1428	› **Modular Hybrid Powertrain:** Modular object-oriented architectures for scalable hybrid powertrains › FVV	› Prof Dr Christian Beidl (vkm, Technische Universität Darmstadt) › Dr Veit Held (formerly Stellantis Opel Automobile GmbH)	› R604 (pp. 140–143)
1433	› **Hy-Flex ICE:** Highly-flexible internal combustion engines for hybrid vehicles › FVV	› Prof Dr Stefan Pischinger (tme, RWTH Aachen) › Marc Sens (IAV GmbH Ingenieurgesellschaft Auto und Verkehr)	› R604 (pp. 144–184) › H1338 (2023)
1434	› **ICE2030:** Limits of SI engine efficiency in hybridised powertrains › FVV	› Prof Dr Christian Beidl (vkm, TU Darmstadt) Prof Dr André Casal Kulzer, Prof Dr Michael Bargende (IFS, Universität Stuttgart) Prof Dr Peter Eilts (ivb, TU Braunschweig) Prof Dr Stefan Pischinger (tme, RWTH Aachen) › Arndt Döhler (Stellantis Opel Automobile GmbH)	› R604 (pp. 100–139)
1440	› **Constraint Effect in Component Design:** owance for the crack-tip constraint in the design against ductile failure › BMWK/AiF	› Prof Dr Peter Gumbsch (Fraunhofer-Institut für Werkstoffmechanik IWM Freiburg) Prof Björn Kiefer (IMFD, TU Bergakademie Freiberg) › Dr Christian Amann (Siemens Energy Global GmbH & Co. KG)	› R604 (pp. 711–728)
1444	› **Modelling of Metal-graphite Composites:** Modelling for the design of metal-graphite composites under consideration of application-related operating conditions (MeGraVII) › BMWK/AiF	› Prof Dr Niels Modler (ILK, TU Dresden) Prof Dr Matthias Busse (Fraunhofer IFAM Bremen) › Dr Susanne Schrüfer (Rolls-Royce Deutschland Ltd & Co KG)	› R604 (pp. 558–578)
1451	› **Aeroelastic Cascade DELTA II:** Experimental and numerical investigations on the influence of aerodynamic loading and stagger angle on aeroelastic stability of combined bending and torsion mode shapes of compressor blades › BMWK/AiF-CORNET	› Prof Dr Dieter Peitsch (ILR, TU Berlin) Prof David Nowell (VUTC, Imperial College London) › Dr Sabine Schneider (Rolls-Royce Deutschland Ltd & Co KG)	› R604 (pp. 490–523)

Collective intelligence –
FVV members

→ **www.fvv-net.de/en/network/members**

Empowering a moving society –
Participating research and technology (RTD) performers

→ **www.fvv-net.de/en/network/rtd-performers**

Science for a moving society

New research programme

FVV's innovation and transfer network is all about dynamism, future, responsibility and power. Pre-competitive fundamental research produces sustainable, environmentally friendly and climate-effective technology solutions.

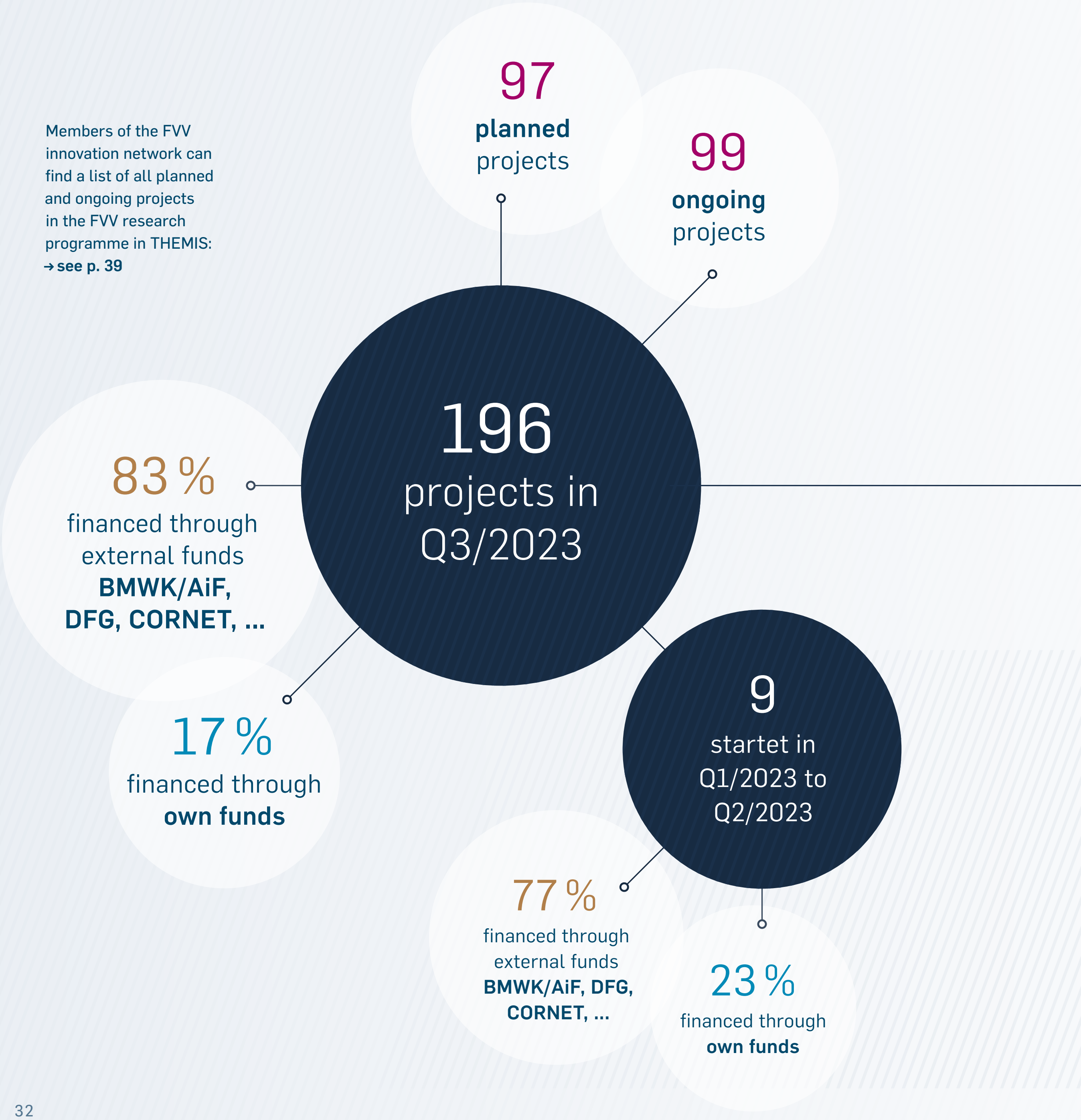
Industrial Collective Research is pre-competitive, forward-looking and open to all topics. FVV's pre-competitive research enables companies to solve shared technology problems and issues, such as on efficiency, life cycles, materials and the circular economy, at a systemic and component level on a sound scientific basis.

Unlike other transfer and technology platforms, FVV is a ›collaborative undertaking‹: industry-oriented research can only succeed where it is developed and designed together. That is why the expert groups come together on the second day of our transfer and networking event to determine their shared need for research and design projects accordingly, guided by experienced members.

Planned and ongoing projects // Status: 03.07.2023

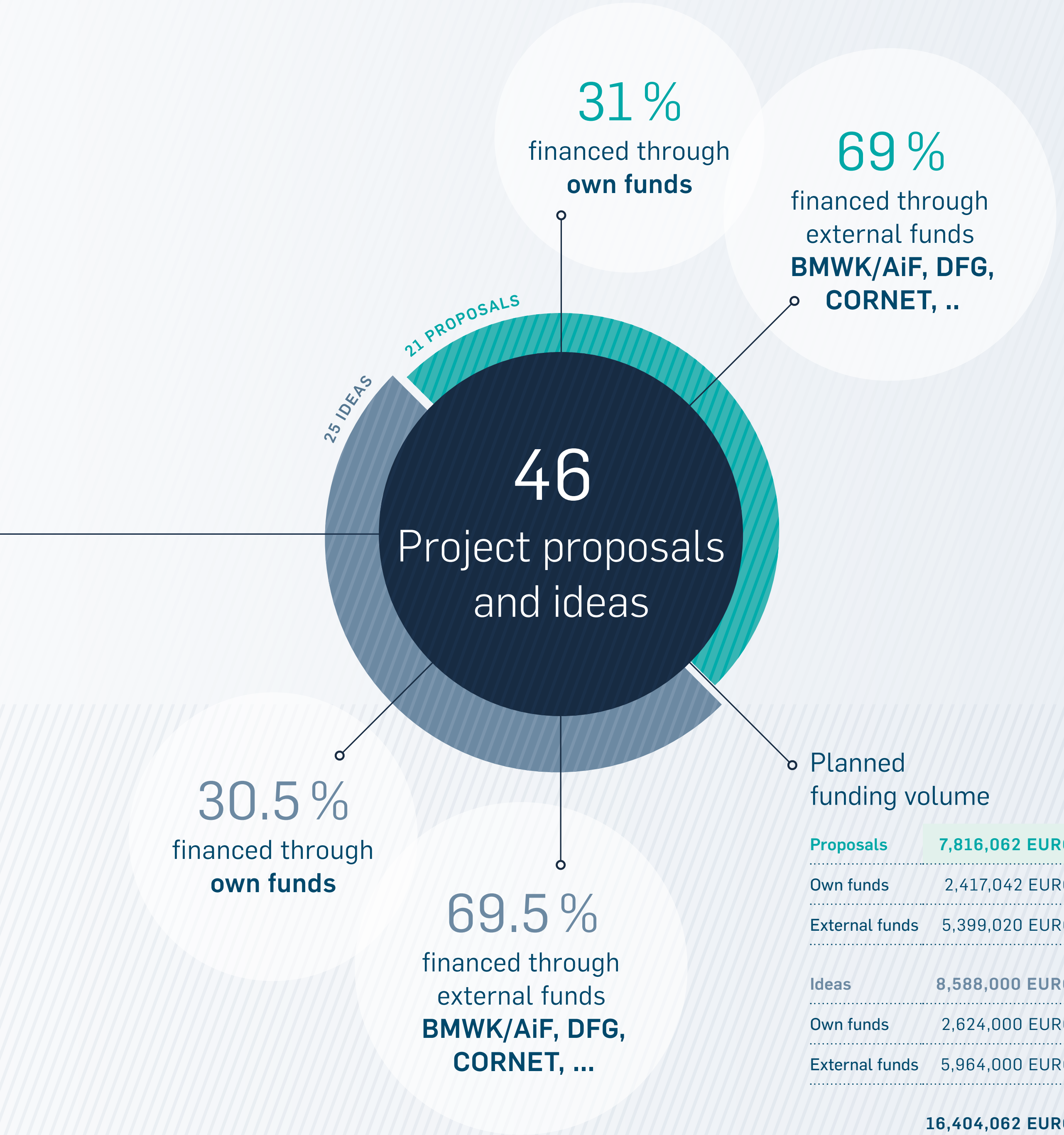
The pre-competitive project work of the FVV enables collaborative research to be performed on fundamental questions, thus allowing the ever stricter requirements regarding materials, fuel efficiency and environmental friendliness to be met. In doing so, the FVV research programme also contributes to enhancing the competitiveness of its member companies.

Members of the FVV innovation network can find a list of all planned and ongoing projects in the FVV research programme in THEMIS:
→ **see p. 39**



New project proposals and ideas // Stand: 02.06.2023

In spring 2023, a total of 25 new project ideas and 21 project proposals were up for discussion in the expert groups' face-to-face meetings in Würzburg and in the written silence procedure. The following package, with a planned funding volume of €16.4 million, was submitted to the FVV Board for final approval.



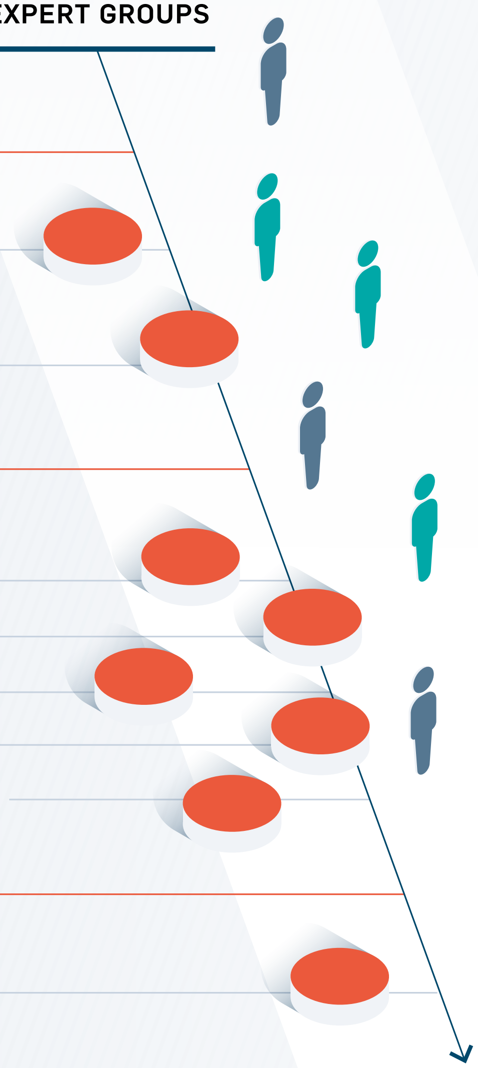
Planned funding volume

Proposals	7,816,062 EURO
Own funds	2,417,042 EURO
External funds	5,399,020 EURO
Ideas	8,588,000 EURO
Own funds	2,624,000 EURO
External funds	5,964,000 EURO
	16,404,062 EURO

Scientific coordination

Together we develop ideas for the future. Experts from member companies meet in the groups to identify common research needs and design projects accordingly. The Scientific Advisory Committee of the FVV appoints chairpersons for each group to lead the scientific work.

EXPERT GROUPS



SYSTEM

Energy Infrastructure and Storage

NN

Sustainable Powertrain Systems

Thorsten Oberpenning, Rolls-Royce Solutions

SUBSYSTEMS

Energy Conversion Systems

- → **Engines** | Dr. Christian Weiskirch, MAN Truck & Bus
- → **Electric Motors** | Carsten Weber, Ford-Werke
- → **Fuel Cells** | Dr. Volker Formanski, BMW Group
- → **Turbo Machines** | Dr. Dirk Hilberg, Rolls-Royce Germany
- → **Zero-impact Emissions** | Dr. Volker Schmeißer, Daimler Truck

COMPONENTS

Materials Science and Recycling

Dr. Dieter Eppinger, SEG Automotive Germany

See also:
»Make it new – Science for a moving society« (ToR)
→ www.fvv-net.de/en/

Terms of references (ToR)

The assignment of research topics to the expert groups, which replace the former planning groups, is made along the system cascade of the V-model.

SYSTEM

Energy Infrastructure and Storage

Interaction of energy sources and system components, energy infrastructure and external storage

→ Chemical energy carriers and alternative fuels beyond application
→ Standardisation → Life cycle analyses

+ General issues related to demand and availability of energy sources / carriers
+ Production, quality, distribution and availability of hydrogen, electricity-based and alternative fuels
+ Standardisation topics on future energy carriers and related issues such as infrastructure and storage
+ Life cycle assessment (LCA)
+ Development of collaboration projects with other institutions to serve the interests of FVV members (e. g. workshop with the fuel / energy industry, ...)

Sustainable Powertrain Systems

Road / rail vehicles: classic powertrains (ICEV), hybrid / electrified powertrains (PHEV, BEV, FCEV), aircraft engines, marine propulsion, mobile machinery, power systems

→ Energy storage within the application
→ System efficiency → Air pollution, global warming, noise, sound, radiation
→ E-machine combined with battery

+ Questions on energy storage in the aforementioned applications
+ System efficiency of energy conversion processes e. g. charging, system control / regulation, sensor technologies, ...
+ Thermal management
+ Zero-impact emissions, greenhouse gas emissions (e. g. CO_2), noise, sound, electromagnetic compatibility (EMC)
+ E-machine combined with battery / ICE [interface to E-MOTIVE platform]
+ Impact of legal, social and political requirements onto powertrain systems, circularity
+ Development / engineering of tools for i. e. the system architecture and interaction of powertrain assemblies

Energy Conversion Systems

Innovative and / or optimised energy conversion systems minimising environmental impact and maximising process efficiency and engine performance

SUBSYSTEMS

→ Engines

+ All conventional engine development topics
+ Optimisation and development of new energy conversion processes focusing on e. g. increasing process efficiency of future varieties of fuels (including use of hydrogen)
+ Reducing the environmental impact
+ Process-focused adaptation of related components and (sub-) assemblies
+ Effects of increasing electrification to the ›engine‹ subsystem and its aggregates
+ Digitalisation
+ Development and improvement of related development / engineering tools based on changing and adopting application / subsystem requirements

→ Electric Motors [interface to E-MOTIVE platform]

+ Improvement of electrical motor properties in mobile applications
+ Electrical energy storage systems (battery)
+ Power electronics of the electrical motor and electrical energy storage system
+ Application-focused adaptation of related components and (sub-) assemblies
+ Development and improvement of related development tools e. g. simulation tools, measurement and testing methods

Energy Conversion Systems

Innovative and / or optimised energy conversion systems minimising environmental impact and maximising process efficiency and engine performance

SUBSYSTEMS

→ Fuel Cells [interface to E-MOTIVE platform]

+ Air and hydrogen system path, media conditioning and purification
+ Thermal management of the fuel cell stack
+ Optimisation of fuel cell specific components and (sub-) assemblies e. g. ion exchanger, compressors, …
+ Research on materials at fuel cell specific conditions and effects, e. g. on bipolar plates, membranes, sealings concerning stack performance, loading characteristics, ageing (durability, degradation), humidification, …
+ Stack performance / efficiency improvements e. g. performance effects of component and assembly tolerances
+ Safety requirements and definitions
+ Development of defined evaluation methods towards industry standards (generic, ›best practice‹)
+ Technology comparison PEM, High-temperature PEM, SOFC
+ Development and improvement of fuel cell specific development tools e. g. simulation tools, measurement methods (e. g. impedance analysis)

→ Turbo Machines

+ All conventional turbomachinery development topics
+ Optimisation of aerodynamics
+ Optimisation of turbomachinery specific components and (sub-) assemblies
+ Research on materials of turbomachinery specific conditions and effects; e. g. high-temperature, loading characteristics, ageing, resonances, use of hydrogen
+ Development and improvement of turbomachinery specific development tools

Energy Conversion Systems

Innovative and / or optimised energy conversion systems minimising environmental impact and maximising process efficiency and engine performance

SUBSYSTEMS

→ **Zero-impact Emissions**

- Exhaust aftertreatment concepts, systems and components
- Alternative aftertreatment system technologies and approaches
- Effects of the use of alternative fuels and operating liquids
- Interactions of exhaust components, primary and secondary exhaust species
- Non-exhaust emission evaluation of all mobile applications (incl. electrified), e.g. brake dust, tyre abrasion, …
- Interaction emission and immission / air quality
- Carbon capture approaches and technologies
- Development and improvement of related development tools, e.g. simulation tools, measurement and evaluation methods

Materials Science and Recycling

All conventional topics on materials research in connection with new energy sources, production methods and recycled materials

COMPONENTS

→ Strength → Tribology → Recycling

- Tribology, strength, fatigue models and improvements
- Properties, strength and fatigue characteristics of materials for electric powertrains (e.g. copper)
- Durability and robustness of electrically isolating materials (e.g. aspect of partial discharge, …)
- Impacts and interactions on components and (sub-) assemblies caused by novel energy types (e.g. hydrogen, e-fuels, methanol, …)
- Components made by additive manufacturing, their properties and related method approaches
- Material properties impact of recycled materials
- Energy footprint of components and assemblies depending on material and manufacturing process, circularity
- Development and improvement of group related development tools e.g. simulation tools, measurement and evaluation methods

THEMIS Database

Members of the FVV innovation network can find a list of all planned and ongoing projects in the FVV research programme and dates for the discussion groups, workshops and project user committees in THEMIS.

Project list

Status: 03.07.2023

Research programme

Status: always up-to-date

Meeting dates

Status: always up-to-date

The publication ›**The FVV Transfer + Networking Event | Spring 2023**‹ is available online:

→ **www.fvv-net.de/en/ | Transfer | Projects | Transfer reports**

Science for a
moving society

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Transfer // Industrial Collective Research (IGF) empowers companies to solve joint research and technology problems on a science-based approach. It provides access to a continuous stream of new knowledge they can use to create their own products, processes and services. Industrial research and development benefits from the fact-/field-based collaboration with the science community, universities and non-profit research institutions, on the future of technology. This creates innovative power in industry and excellence in research, teaching and learning.

Networking // The research implemented by the FVV is based on a long-term cooperation between the partners. In spring and autumn, around 300 experts meet regularly at the FVV Transfer + Networking Events. This report from the science series FVV Prime**Movers.** Technologies. summarises the main results.

FVV e V

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